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Seventy Years of Computing in the Nuclear Weapons Program

Bill Archer

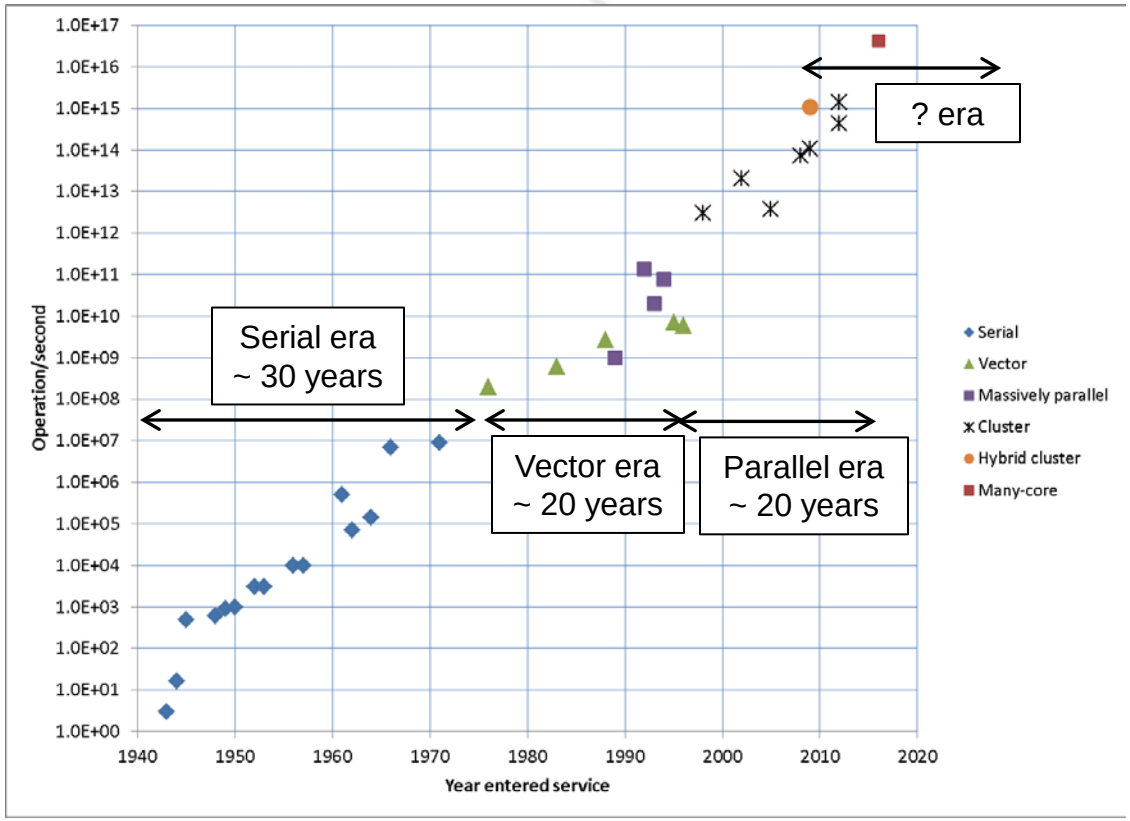
Advanced Simulation and Computing Program Director

Los Alamos Historical Society

January17, 2015

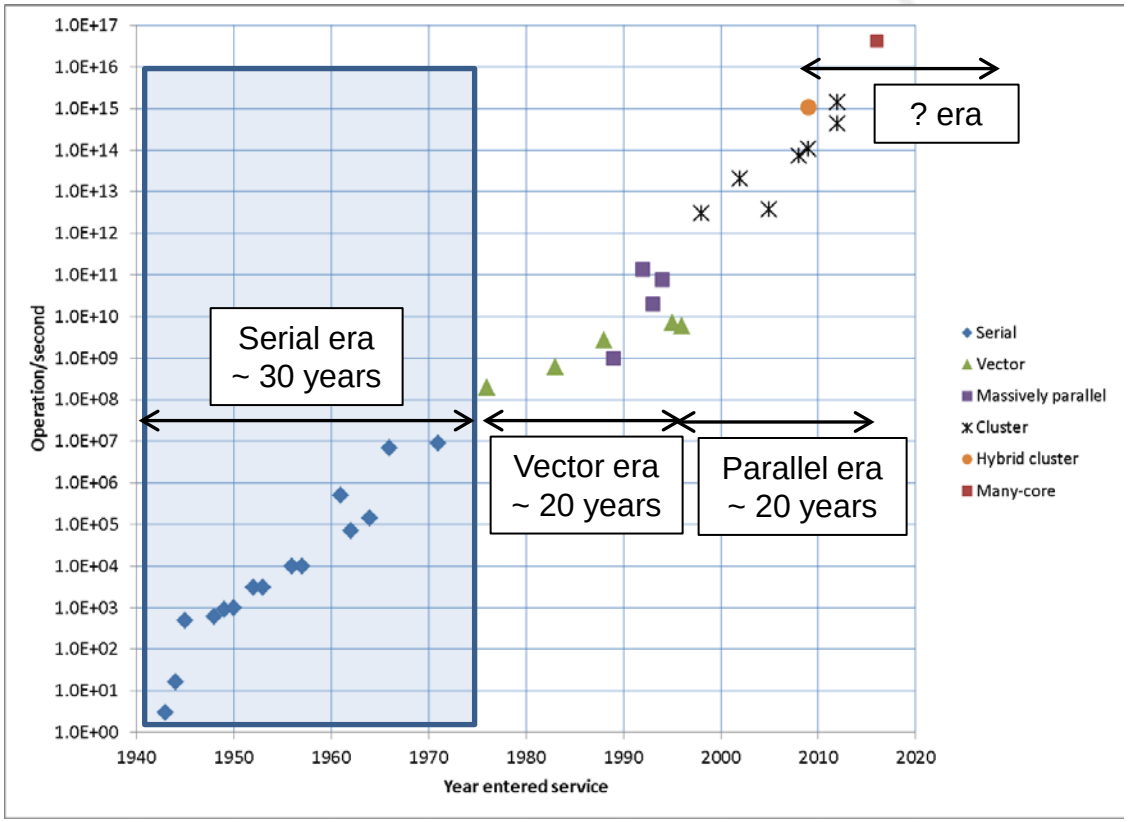
Los Alamos has been at the forefront of computing since 1943

- Los Alamos has both driven, and taken advantage of, increased computing capability
- A 16 order-of-magnitude increase in capability in 70 years!



Size of a virus compared to the orbit of the moon!

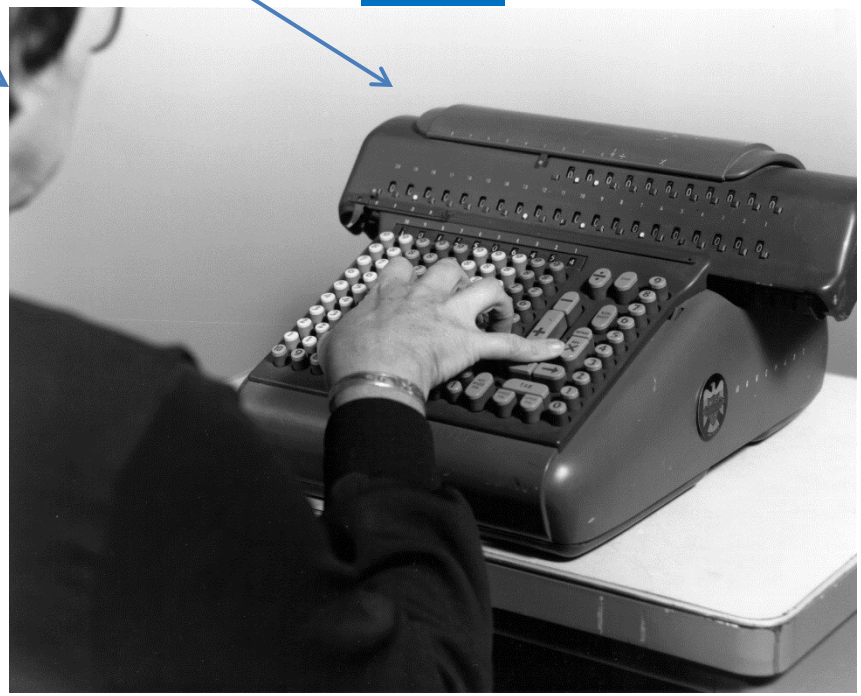
The serial era began in 1943



Los Alamos used the best computers of the era for calculating hydrodynamics.

- Marchant calculator
- Computer
- Slide Rule

3 Ops



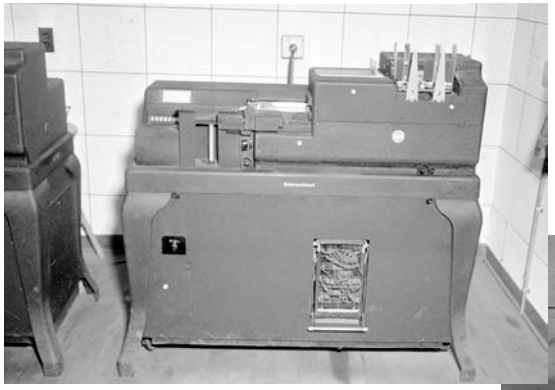
Ops is Operations per second

IBM Punch Card Accounting Machines (PCAM) were used for hydrodynamic calculations, 1944 to 1950

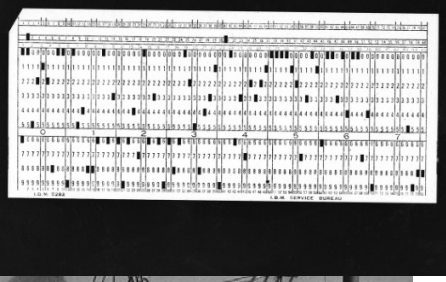
Los Alamos NATIONAL LABORATORY EST.1943

16 Ops

IBM 601 Multiplier

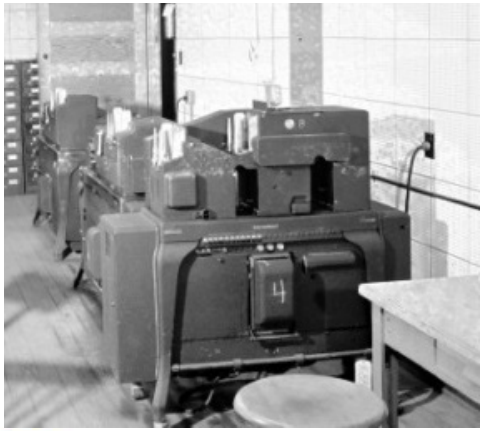


IBM Punch Card



IBM 405 Accounting Machine

IBM 513 Reproducing / Summary



IBM 081 Card Sorter

IBM 031 Key Punch

IBM 077 Collator

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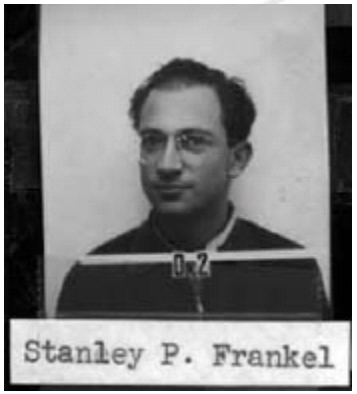
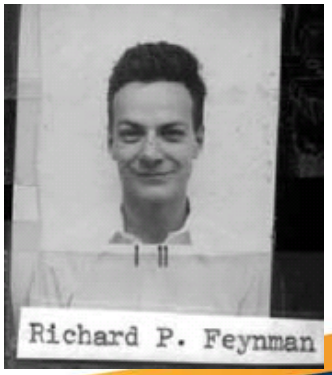
Los Alamos accidentally created the first computer geeks.



- Stanley Frankel and Eldred Nelson developed the PCAM for scientific computing

- They became enamored with discovering what could be done … and forgot what must be done

- Nick Metropolis and Richard Feynman took over the computing center



"Well, Mr. Frankel, who started this program, began to suffer from the computer disease", R. Feynman

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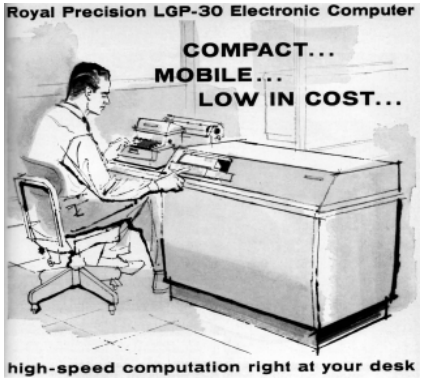
Nelson and Frankel were drivers of the early West Coast computer industry.

- With Serber, in 1942 they worked out the neutronics equations in LA-1 (The Los Alamos Primer)
- They formed the first computer consulting firm in 1947 in Los Angles, California
  - Developed foundations for missile navigation systems in the Northrop Snark cruise missile
- Frankel lost his clearance in 1949, his father was a communist
  - Designed the first personnel computer while at CalTech
  - Sold by Librascope as the LGP-30 in 1956
  - LGP-30 strongly influenced the first HP desktop calculator
- Nelson lead the development of
  - The first airborne digital computer at Hughes Aircraft
  - The first process control computer at TRW for a refinery
- And much more!



Ad in Proceedings of the IRE in May, 1957

The first calculation on ENIAC, one of the first electronic computers, was by Los Alamos

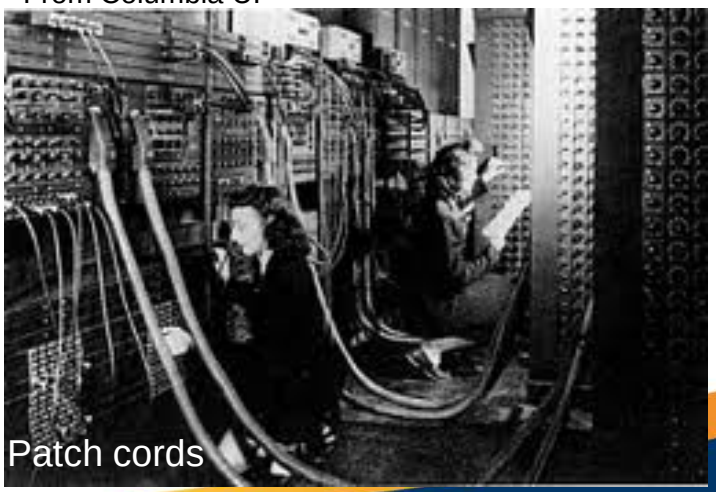
Los Alamos NATIONAL LABORATORY EST. 1943

500 Ops

- The first calculation on ENIAC, 1945
  - First thermonuclear calculation, for the Super bomb
  - John von Neumann, Stan Frankel, Anthony Turkevich
- Monte Carlo method developed at Los Alamos, 1947
  - Uses random particle method to solve nuclear problems
  - By Stan Ulam and John von Neumann
- First ever Monte Carlo calculation, on ENIAC in 1948
  - John von Neumann, Klara von Neumann, Herman Goldstine, Adele Goldstine, Nick Metropolis

18,000 vacuum tubes

From Columbia U.



Patch cords

Anthony Turkevich

UNCLASSIFIED

The first nuclear burn code was developed on an IBM prototype

- Richtmyer and von Neumann, 1947-1951
- Was the first shock hydrodynamics code
  - Used too much memory for ENIAC
  - Developed artificial viscosity for shocks
  - Used Monte Carlo method
- SSEC was IBM's first electronic computer
- Los Alamos hijacked almost every 1st generation machine
  - National Bureau of Standards, Census Bureau

Robert Richtmyer

IBM Selective Sequence Electronic Calculator (SSEC), their first large-scale electronic machine,1948 - 1952

600 Ops

13,000 vacuum tubes

Pictures from IBM

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MANIC I & II were the Los Alamos first generation systems

- Hand built by team lead by Metropolis
- MANIAC I in service 1952 to 1957
  - About 1,000X faster than PCAM
  - Cathode-ray Williamson tubes for memory
  - Used for hydrodynamics & Monte Carlo
- MANIAC II in service 1957 to 1977
  - Had floating point
  - Over 5000 vacuum tubes
  - Overcome by the IBM 704
  - Mainly used for computer science research

3 kOps

MANIAC I

10 kOps

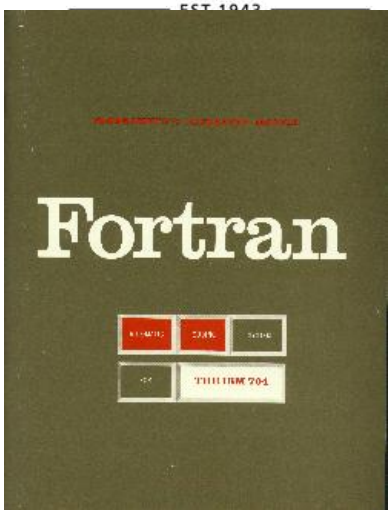
MANIAC II

The IBM 701 and 704 machines were revolutionary

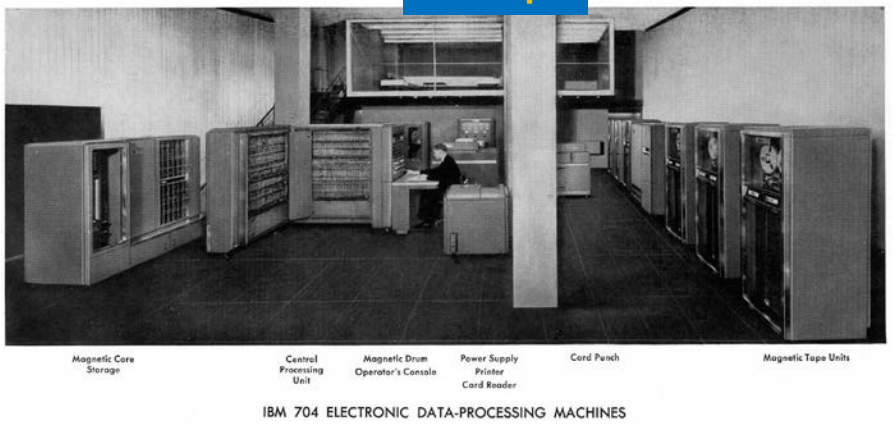
- First LANL use of commercial computers
- Programmed in assembler
  - A big step forward from patch cords!
- 701 used a cathode-ray for memory
  - It would crash every time a truck drove by on Trinity
  - Required backups every 10 minutes!
- 704 had floating point hardware and magnetic core memory
- First one-point safety calculations, 1955
- FORTRAN on 704, 1957

3 kOps

IBM 701 – serial #2 to Los Alamos (#1 replaced SSEC); 1953-1956



10 kOps

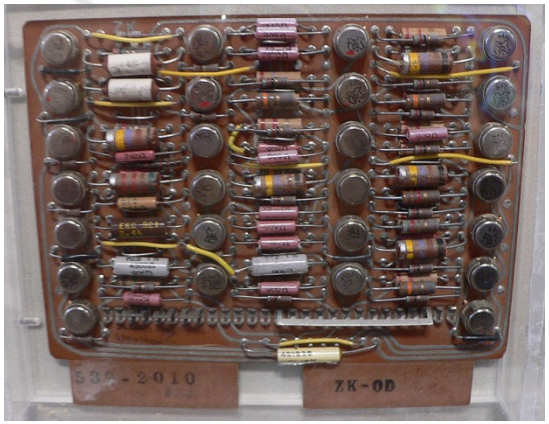


IBM 704 – serial #1 to Los Alamos; 1956-1963

IBM 7030 Stretch was IBM's first computer built of transistors

500 kOps

- A 5-year co-design effort by LANL and IBM
- IBM's first transistorized computer
- LANL took serial #1
- World's fastest computer, 1961 to 1964
- Stretch was mainly a computer science research project;
  - IBM used concepts for the IBM 360
- Weapons work was on the IBM commercial descendants
  - IBM 7090 (1962-1964)
  - IBM 7094 (1964-1970)
  - About 8X faster than the IBM 704.
- The first online mass storage system, the IBM 1360 Photo Store, is installed, 1966



IBM 7030 circuit board

IBM 7030

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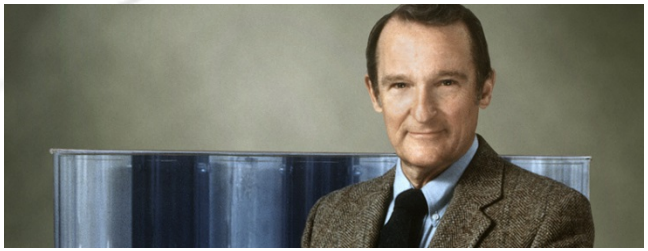
Control Data Corporation (CDC) systems were used for 20 years



Courtesy of Cray, Inc.

7 MOps

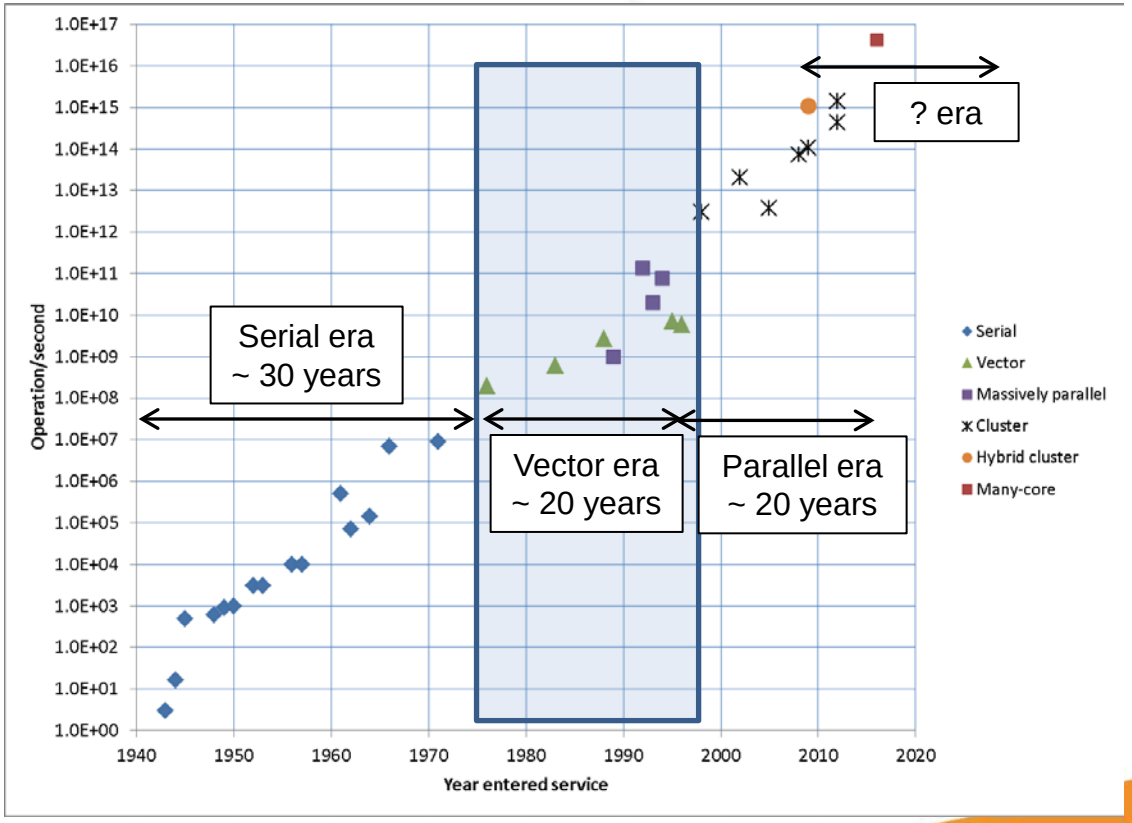
- CDC 6600: fastest type computer, 1964-1969
  - First liquid cooled system at Los Alamos
  - At LANL, 1966-1981
- CDC 7600: fastest type computer, 1969-1976
  - At LANL, 1971-1985
- Both were designed by Seymour Cray
- 2D implosion simulations routine by 1968

9 MOps

The vector era began in 1976

1981: Los Alamos Scientific Laboratory becomes Los Alamos National Laboratory

- First parallel type calculations
  - Same operation on several numbers
- Vector machines required rewriting the weapon codes



The Cray vector systems were used by the weapons program for about 30 years

- Cray 1 was co-designed with Los Alamos over a 6 year period
  - Los Alamos had serial #1
  - Fastest machine, used integrated circuits
  - Bare iron, LLL wrote operating system and LASL wrote compilers, math and graphics libraries
- Cray XMP arrived in 1983, 4 CPU
- Cray YMP arrived in 1988, 8 CPU
- LANL kept a T94 until 2003 and a J90 until 2004
- A practical 2D primary explosion code available,1991

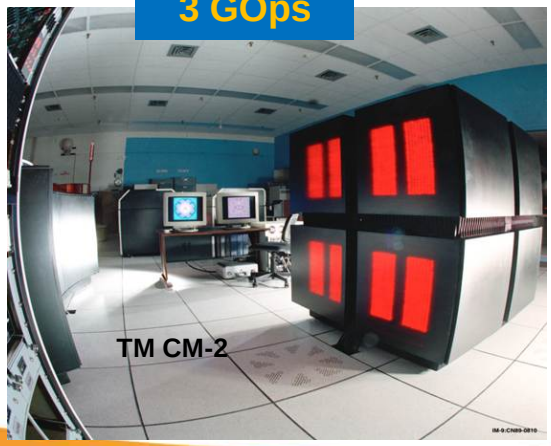
Massively parallel systems were a bridge technology

- No vector units!
- Computer science of parallel programming
- Thinking Machines CM-2
  - 65,536 single-bit processors, 1989
- Thinking Machines CM-5
  - 1024 Sparc processors, 1992
  - CM-5 was fastest machine
- Cray T3D
  - 2048 Alpha processors, 1994

19 GOps

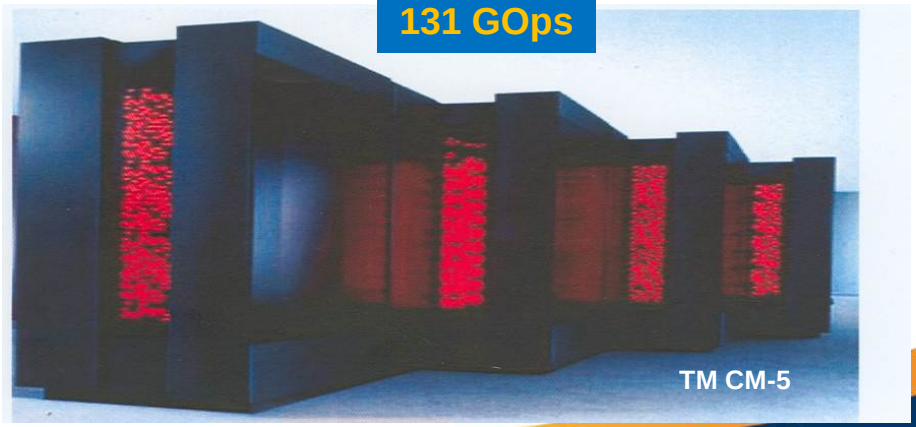
Cray T3D

3 GOps



TM CM-2

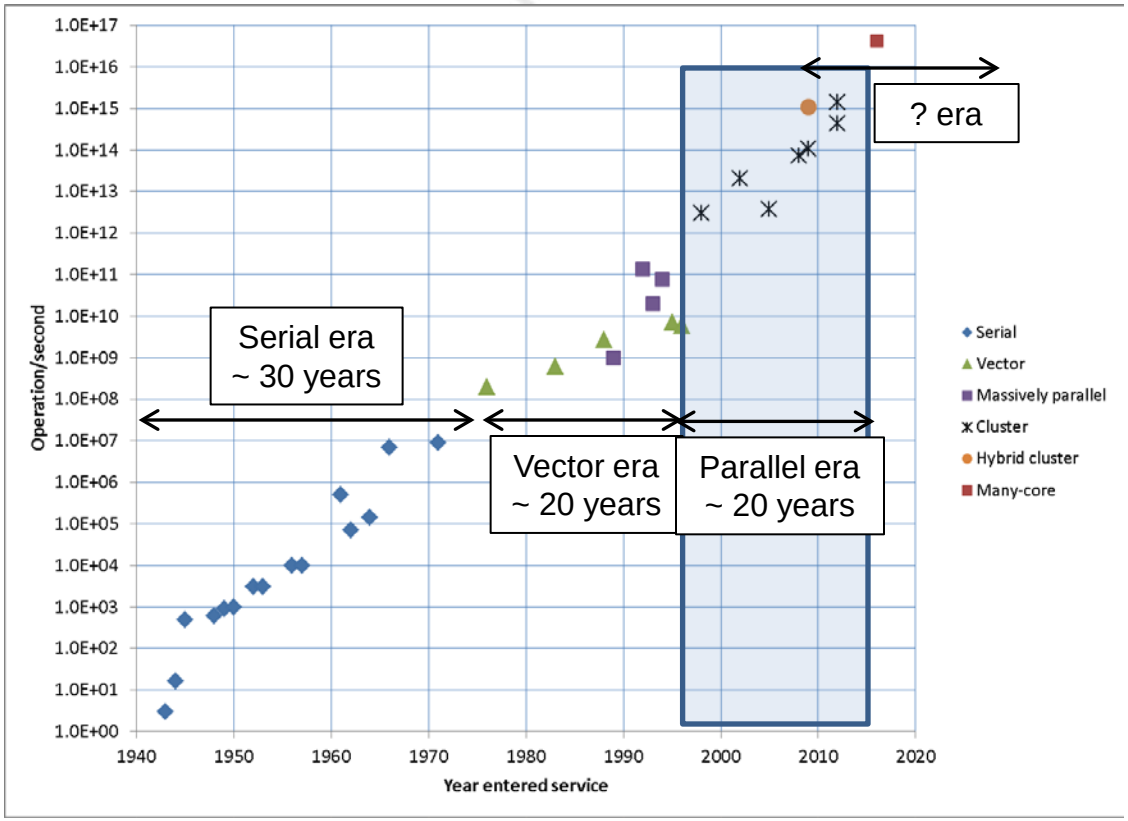
131 GOps



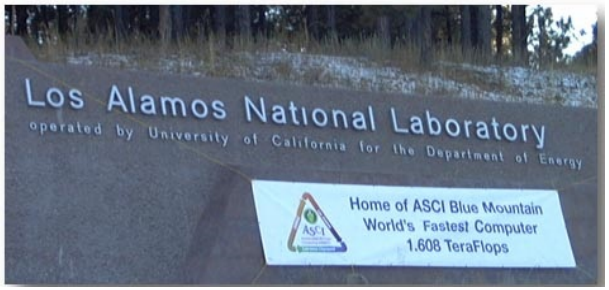
TM CM-5

The 1990's was a time of change, resulting in parallel cluster systems

- End of U.S. nuclear testing in 1992
- Change in computing technology
- Caused nation to found ASCI, 1995
  - Accelerated Strategic Computing Initiative
  - Vision was a big leap forward in computing, both machines and codes; focused on 3D



SGI Blue Mountain was LANL's first commercial off-the-shelf cluster



48 SGI Origin 2000, a total of 6,144 CPUs; compare to the J90 with 32 CPUs

7 TOps

- For a short time Blue Mountain was fastest machine at 1.6 TF
  - Eventually upgraded to 3.1 TF, then #2
- SGI bought Cray in 1996
- Used Cray's version of LANL's *HIgh Performance Parallel Interface*
- Showed the need for large parallel file systems
  - Launched the large, parallel, file system industry which lead to global parallel file system environments in use around the world today

The new clusters were so big they needed a new building!

- Nicolas Metropolis Strategic Computing Complex (SCC)
- The SCC has a 43,500 sq ft (1 acre) computer floor
- Entire floor is air cooled

The Q machine taught us how to use global parallel file systems.

- The Compaq/HP Q system
  - 8192 processers, #2
  - First machine with a global parallel file system
  - Proved that a global file system was viable
  - First system installed in the SCC
- Parallel, 3D, interactive visualization was developed by ASCI

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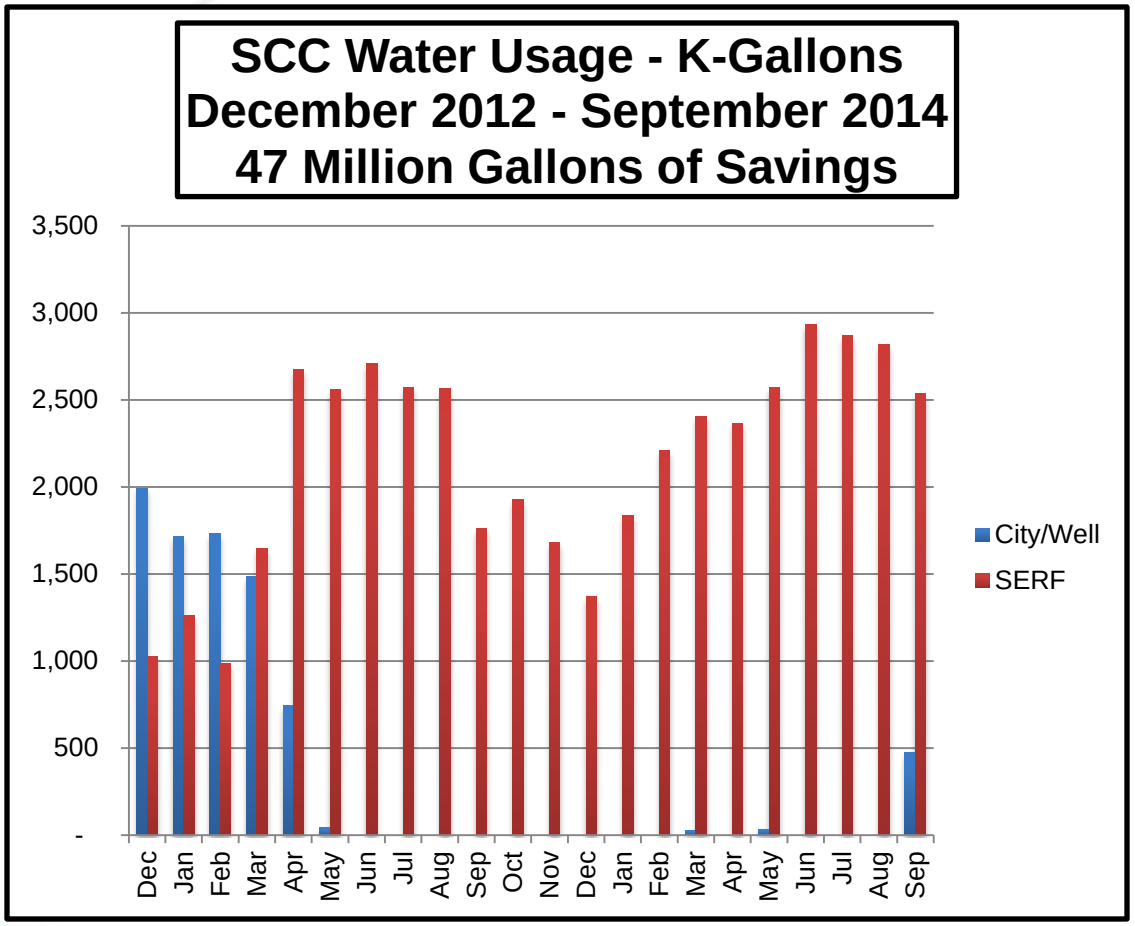
SERF is providing most of the cooling water to the SCC for the supercomputers

Sanitary Effluent Reclamation Facility



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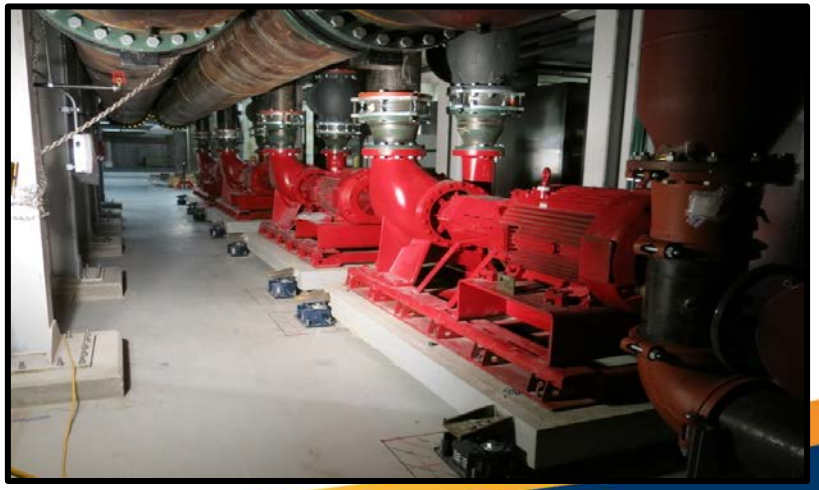
SCC cooling infrastructure is being increased to accommodate ASC systems through 2025

- Current work will accommodate systems through about 2025
- Increasing power to about 20MW
  - From about 15MW
- Adding 12MW of warm water cooling
  - 75^{o} water to computer

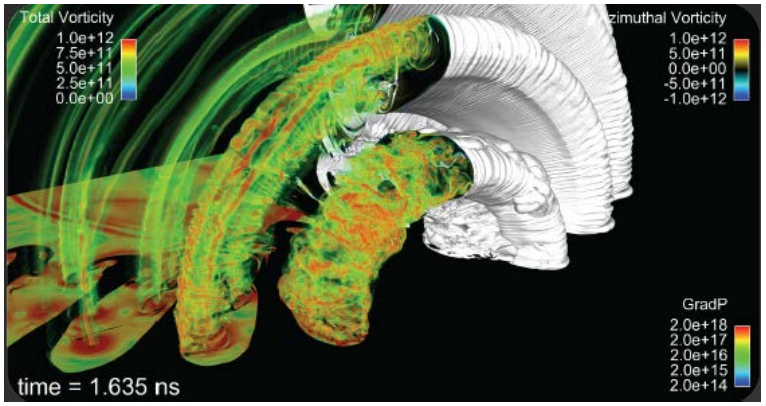


Cielo is the first system to routinely be used for 3D stockpile simulations

- A standard cluster architecture
  - 107,264 Intel processors
  - 0.38 PB of memory
- Designed for production usage by LANL, LLNL, and SNL

1.4 POps

Cray XC-30, Cielo



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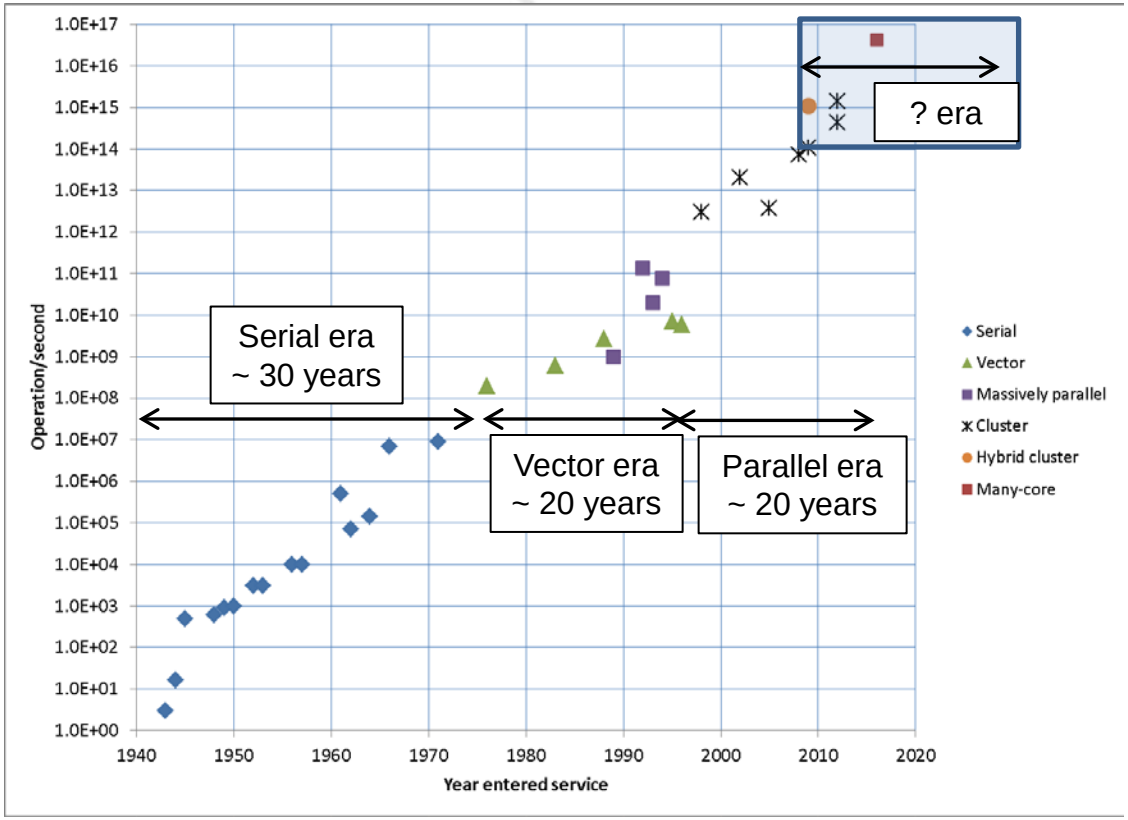
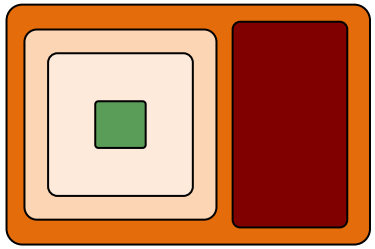
We are entering a new era of computing that is still being defined

- Los Alamos is one of the leaders of the changes with Roadrunner and Trinity



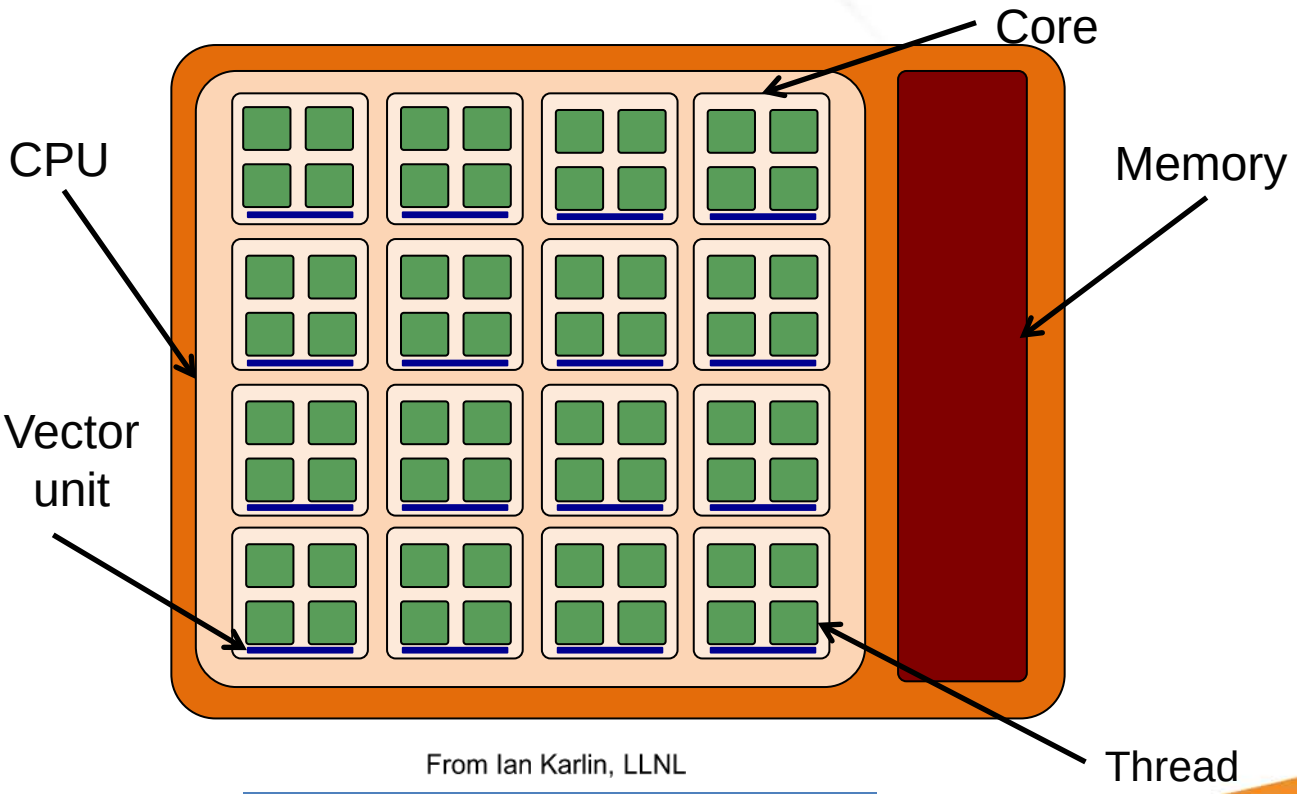
On node parallelism is the challenge on next-generation systems; driven by power usage

2000
1 cores X 1 threads/core
= 1 threads
(no vectorization)



ASCI codes
started with this!

What Industry Provides Today
16 cores X 4 threads/core = 64 threads **plus** vectorization



From Ian Karlin, LLNL

How do we use all of this?

Roadrunner was the first hybrid supercomputer and the first to deliver 1 PetaFlop/s

- First supercomputer built from non-traditional commodity processor
  - Modified Cell accelerators (12,960) + CPUs (12,960)
- Demonstrated that a hierarchical architecture is a path forward
  - Now many other machines are using accelerators

Taught LANL staff about hierarchical programming

Trinity is designed to support the most demanding stockpile simulations

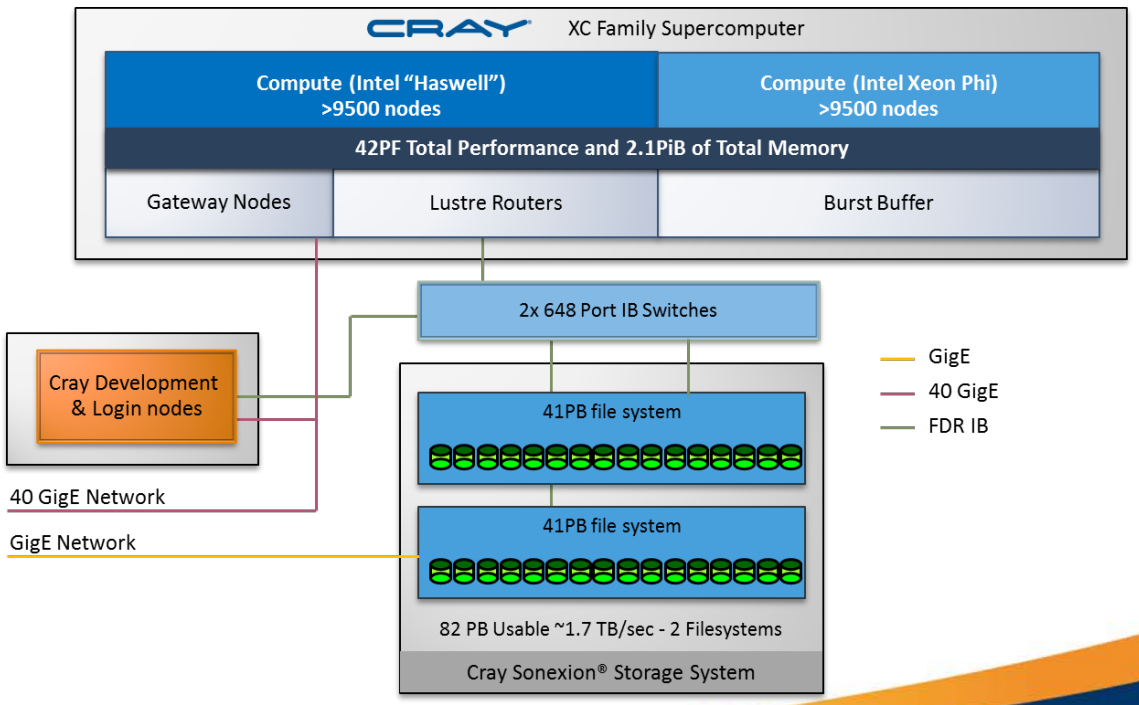
Los Alamos NATIONAL LABORATORY EST. 1943

TRINITY

- Contract signed In July 2014 with Cray for an XC40 system
  - 2 PB memory
  - A many-core architecture
- Deliveries in 2015 and 2016
- Will allow 3D full-system simulations
- Push transition of weapon codes to next generation architectures

40 POps

Cray Compute and Storage Infrastructure for "Trinity"



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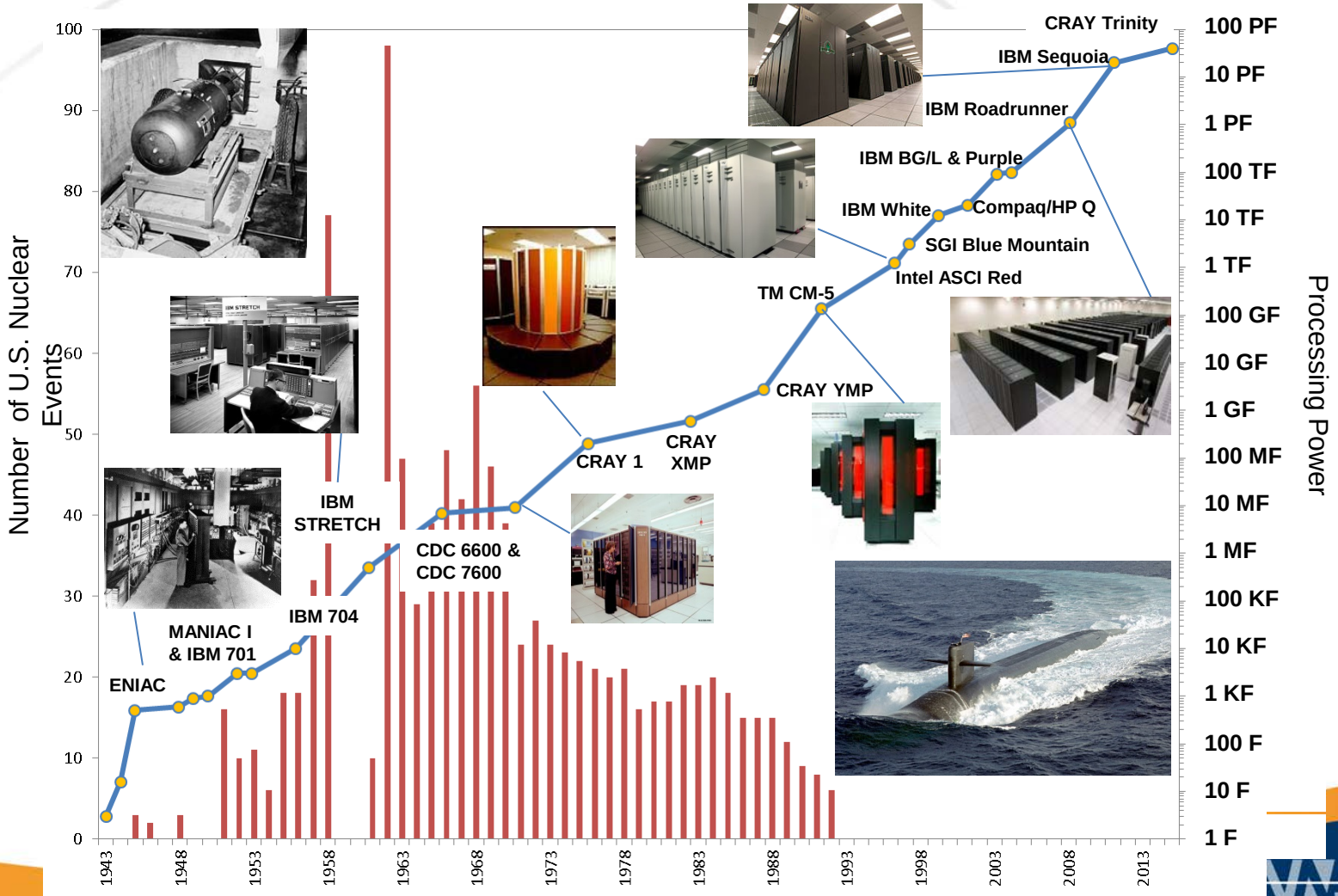
Computing has always been a core component of the weapons program



Abstract

Los Alamos has continuously been on the forefront of scientific computing since it helped found the field. This talk will explore the rich history of computing in the Los Alamos weapons program. The current status of computing will be discussed, as will the expectations for the near future.

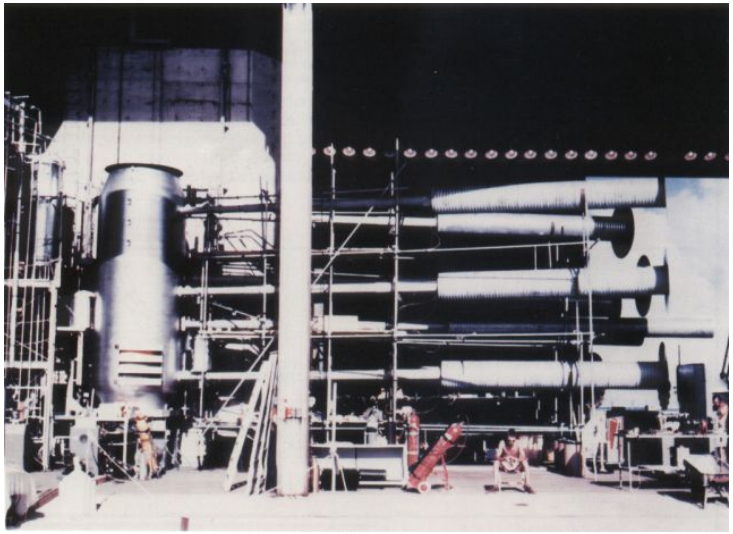
Biography

Dr. Bill Archer received his doctorate from the University of Oklahoma in 1988 for research on computational quantum chemistry carried out at Los Alamos. He was a post-doc at Rice University, a superconducting magnet designer at the Superconducting Super Collider, and an operations research analyst at the Center for Naval Analyses. While at CNA he was embedded with the Fleet for seven years.

Returning to LANL in 1999 he was project leader for a major integrated design code, studied the history of the weapons program, and has held a variety of line and program management positions in computational physics. He is currently the Program Director for the Advanced Simulation and Computing program that develops the weapon codes and classified high performance computing.

Thermonuclear burn calculations were carried out on the NBS Standards Electronic Automatic Computer (SEAC) machine

- First 2D hydrodynamics code was also the first secondary code, 1951



Ivy Mike Test, 1952

1 kOps

Picture from NBS

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Los Alamos has been at the forefront of developing high-speed network interconnects

- Los Alamos developed one of the first networks, named Hydra, to allow common access to the five CDC machines, 1972
- High-Speed Parallel Interface (HSPI) for inter-computer communication, 50 Mbit/s, 1979-1982
- HIgh-Performance, Parallel Interface (HIPPI), the first gigabit network, 1987
- Infiniband interconnect came out of ASCI work in the late 1990's
- Optical interconnects started by ASCI ~2000

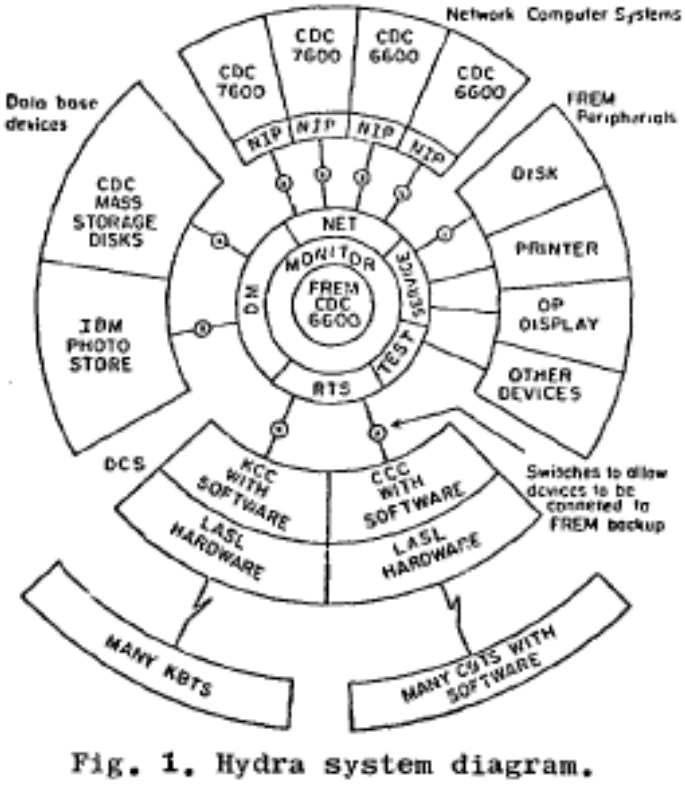

Fig. 1. Hydra system diagram.

Hydra network design, 1972

High-speed interconnects are a standard commercial off-the-shelf technology now